BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 09085

SUBJECT: Thermal Coupling of Oxygen and Water Lines in an Insulated Umbilical - An Analysis - Case 620

DATE: September 30, 1969

FROM: G. M. Yanizeski

[redacted]

ABSTRACT

Gaseous oxygen for AAP EVA flows through an umbilical to a chest mounted pressure control unit (PCU). Thermal coupling between the oxygen line and two water lines in the umbilical tends to stabilize oxygen temperatures. In the analysis, an energy balance, based on an overall heat transfer coefficient between the oxygen line and the two water lines, yields oxygen temperature as a function of position along the umbilical. The overall coefficient is calculated from a finite difference computer model of the umbilical cross section. The analysis indicates that the oxygen temperature exponentially approaches the average water temperature with substantial oxygen temperature changes possible in long umbilicals. Since the presently configured AAP umbilical is long, oxygen temperatures at the PCU will be near the average water temperature.

(NASA-CR-106863) THERMAL COUPLING OF OXYGEN AND WATER LINES IN AN INSULATED UMBILICAL. AN ANALYSIS - CASE 620 (Bellcomm, Inc.) 11 p

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MEMORANDUM FOR FILE

I. INTRODUCTION

During the AAP EVA events, gaseous oxygen flows through a long umbilical to a small, chest-mounted Pressure Control Unit (PCU). Oxygen temperatures at the umbilical entrance can vary somewhat, however, thermal coupling with water lines in the umbilical tends to stabilize oxygen temperatures at the PCU. An analysis to determine the importance of this thermal coupling in the umbilical is presented here. Only the umbilical problem is considered although other effects may be important such as any pressure reduction at the PCU.

As shown in Fig. 1, a proposed umbilical* consists of one oxygen line, two water lines, and a series of electrical leads, all surrounded by several layers of fabric and insulation. The oxygen flows at approximately 9 lbs/hr to the astronaut and then is vented to space. Water for cooling purposes flows to the astronaut at 230 lbs/hr at approximately 41°F and returns to the spacecraft at approximately 51°F.[1]

II. ANALYSIS

The general method of solution is to perform an energy balance on a differential length of oxygen line using an effective overall heat transfer coefficient between the oxygen and water lines. The resulting differential equation is integrated to yield bulk oxygen temperature as a function of position along the umbilical. To complete the solution, the overall heat transfer coefficient is evaluated from a finite difference computer model of the umbilical cross section.

Assumptions

1. The water lines and oxygen line in the umbilical are completely insulated from the external thermal environment.

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*Umbilical configuration has not been finalized.

2. Since water flow rates are relatively high and since the heat capacity of water is relatively high, the water temperatures are essentially constant along the umbilical.

3. Conduction in the axial direction is negligible. In the rubber hoses, radial conduction dominates; and in the gaseous oxygen, the flow term (mass flow rate times specific heat) dominates.

4. An effective, overall heat transfer coefficient H, which is constant over the range of temperatures considered, can be defined.

Energy Balance and Governing Equations

Let the overall heat transfer coefficient H (BTU/hr ft °F) be defined as follows:

$$q = H\ (\bar{T}_w - T)$$

where

q = net heat transfer rate per unit length between the two water lines and the oxygen line.

$\bar{T}_w$ = arithmetic average of the two water temperatures (46°F).

T = bulk oxygen temperature at a given umbilical position.

The terms q and T are functions of position x measured along the umbilical while $\bar{T}_w$ and H have been assumed constant.

At steady state, the summation of heat flow rates into the volume between x and x + Δx, as illustrated in Fig. 2, is zero. Employing the above assumptions, this summation for Δx approaching zero is

$$\dot{m}C_p T - \dot{m}C_p (T + \frac{dT}{dx}\Delta x) + H(\bar{T}w - T)\ \Delta x = 0$$

After simplifying and rearranging, the following ordinary differential equation is obtained:

$$\frac{dT}{dx} = \frac{H}{C_p \dot{m}}(\bar{T}_w - T)$$

Integrating and substituting the boundary condition $T=T_o$ at $x=0$ yields the following expression for bulk oxygen temperature:

$$T = \bar{T}_w + (T_o - \bar{T}_w) \exp\left(\frac{-H}{\dot{m}C_p}x\right)$$

Therefore, the oxygen temperature will approach the average water temperature exponentially.

<u>Calculation of the Overall Coefficient H</u>

To evaluate H, a finite difference model of a simplified umbilical cross section is constructed. (For a comprehensive treatment of the method of finite differences, see Dusinberre, Ref. 2). As indicated in Fig. 3, the two water lines and the oxygen line are divided into 105 isothermal sectors or nodes. Nodes 1 through 99 represent the rubber hoses; nodes 100, 101, and 102 represent the fabric cover at the contact zone between hoses; and nodes 103, 104, and 105 represent the warm water, cool water, and gaseous oxygen flow cross sections respectively.

For the evaluation of thermal conductor paths, a 1/8 inch contact zone between hoses and a 1/64 inch fabric thickness are chosen. Approximate conductivity values selected for the rubber and the fabric are 0.1 BTU/hr ft °F and 0.04 BTU/hr ft °F respectively. Contact coefficients are not considered. Although more precise information is desirable here, the values used are at least typical and probably as accurate as any now available.

A local heat transfer coefficient h, as defined by Newton's law of cooling, is used for calculating conductor paths between fluid nodes and adjacent solid nodes. For the gaseous oxygen, with a Reynolds number R_n = 12,000 and a Prandt number P_r = 0.72, the experimental Deissler plot[3] yields an h value of 23 BTU/hr °F ft^2. The entrance region where h approaches this constant value is short and is ignored; and variations with temperature and pressure are small enough to be ignored in this calculation.

For the warm water line with R_n = 2,900 and P_r = 9.7, and for the cool water line with R_n = 2,500 and P_r = 11.6, flow is in the transition region between the smooth laminar and fully developed turbulent regimes - a region of flow where accurate data is difficult to obtain. The Deissler plot is not applicable for this flow condition; therefore, a similar plot by Siedler and Tate(3) is used. This second plot gives the coefficient based on a logarithmic mean temperature difference; however, this coefficient for large length to diameter ratios is nearly equal to the local coefficient. Thus, for the warm and cool water lines respectively, h values of 172 BTU/hr ft^2 °F and 135 BTU/hr ft^2 °F are used.

III. RESULTS

The finite difference model is solved on a computer using the Chrysler Improved Numerical Difference Analyzer (CINDA),* which is a large program designed to solve thermal analog models presented in a network format. In this case, the network is the assembly of nodes and conductors representing the umbilical cross-section. Due to the ease of solving these networks with CINDA, a relatively fine breakdown of the umbilical cross section is used. For this case, H is calculated to be 0.085 BTU/hr ft °F.

Substituting H, $\bar{T}w$ and $\dot{m}C_p$ into the expression for bulk oxygen temperature yields

$$T = 46°F + (T_o - 46°F) \exp(-.044x)$$

where x is the distance along the umbilical measured in feet.

To illustrate the significance of the thermal coupling, oxygen entering a 60 ft umbilical with a minimum temperature of -22°F will exit at the PCU within 5°F of the asymtotic value of 46°F. To obtain the same exit temperature of 41°F for a 40 ft. umbilical, the minimum inlet temperature is 18°F, and for a 20 ft. umbilical, it is 34°F.

For the 60 ft. case, the water lines supply 123 BTU/hr to the oxygen. This results in less than a 1°F change in the average water temperature (Assumption 2).

IV. CONCLUSIONS

Despite inherent analytical uncertainties, it is clear that thermal coupling in umbilicals can substantially influence oxygen temperatures. For long umbilicals, the oxygen temperature at the PCU is close to the average water temperature over a wide range of inlet temperatures.

The presently configured AAP umbilical, which is similar to the umbilical analyzed, is long (60 ft.)*, and the oxygen inlet temperature is controlled by a heat exchanger to a small range (approximately 40°F to 70°F). Therefore, oxygen temperatures at the PCU will be near the average water temperature, and there should be no difficulty in maintaining the desired temperature (40°F to 65°F).

George Yanizeski

1022-GMY-cf G. M. Yanizeski

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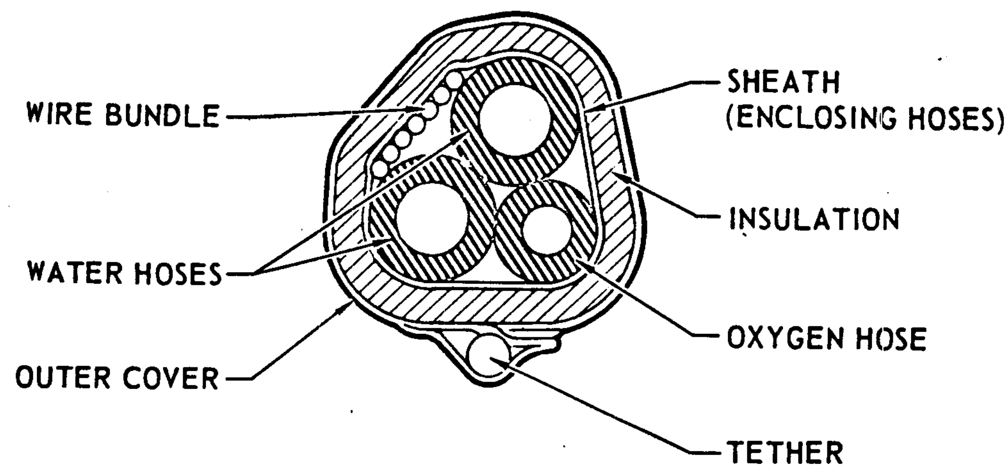
*Umbilical data represent approximate values obtained from telephone conversations with J. T. Brown of MSC and L. C. Calhoun of McDonnell Douglas.

References

1. McDonnell Douglas Briefing Charts, "Airlock Technical Briefing at NASA/MSFC, 31 October - 1 November 1968."

2. Dusinberre, G. M., 1961, Heat Transfer Calculations by Finite Differences, International Textbook Company, Scranton.

3. Bird, R. Byron, Stewart, Warren E., and Lightfoot, Edwin N., 1963, Transport Phenomena, John Wiley and Sons, Inc., New York, pp. 400-402.



WATER AND OXYGEN HOSES ARE FABRIC COVERED, WIRE REINFORCED, SILICONE RUBBER

WATER HOSES ARE 3/8 INCH INSIDE DIAMETER; OXYGEN HOSE IS 1/4 INCH INSIDE DIAMETER.

INSULATION CONDUCTANCE EQUIVALENT TO 3/16 INCH THICK JOHNS MANVILLE MICRO-FOIL TAPE (TYPE 475).

OUTER COVER WILL BE POROUS, ABRASION-RESISTANT, NON-FLAMMABLE MATERIAL SUCH AS BETA CLOTH.

SHEATH ENCLOSING HOSES WILL BE NON-POROUS, ABRASION-RESISTANT, NON-FLAMMABLE MATERIAL SUCH AS ARMALON FABRIC.

THE INSULATION VENTS RADIALLY AND LEAKAGE VENTS AXIALLY.

TETHER IS BRAIDED STAINLESS STEEL CABLE WITH BRAIDED TEFLON OUTER COVER.

FIGURE 1. UMBILICAL CROSS SECTION FROM REF. 1.

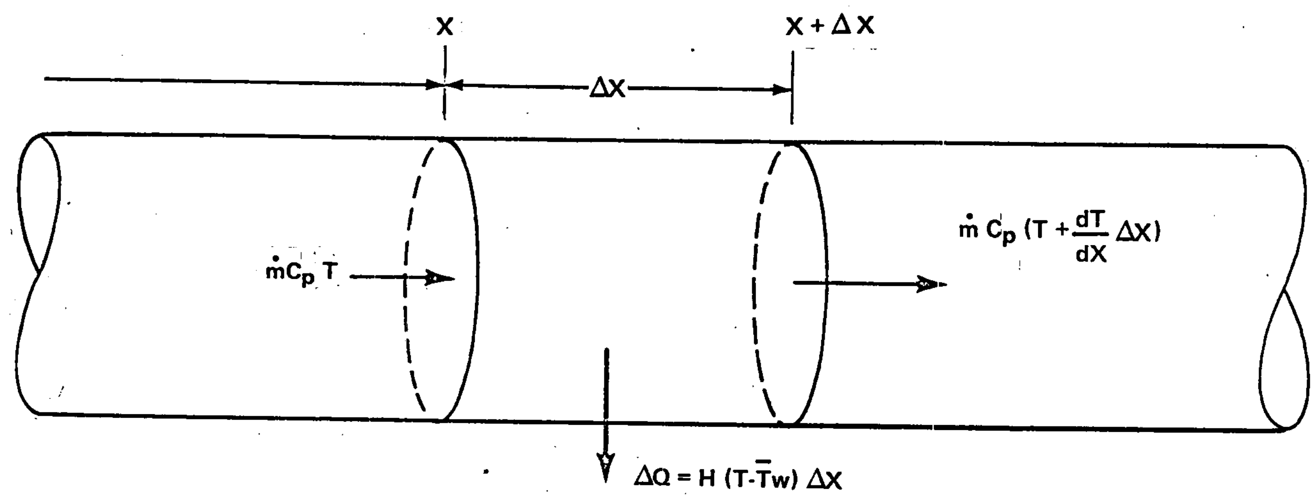


FIGURE 2- ENERGY BALANCE FOR THE OXYGEN LINE

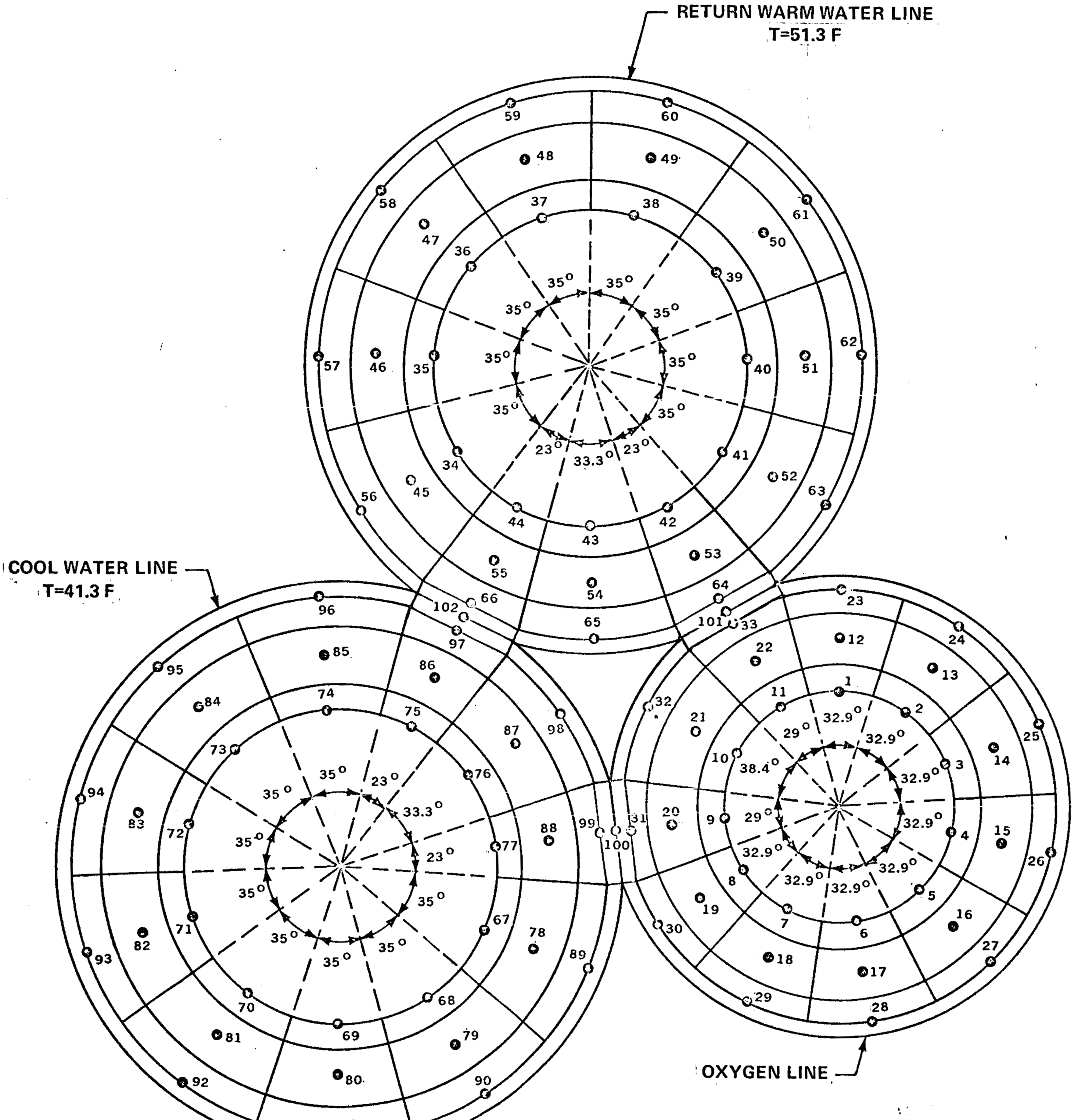


FIGURE 3- FINITE DIFFERENCE BREAKDOWN OF THE UMBILICAL CROSS SECTION

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